The Use of Epifluorescence Techniques to Determine Potential Oil-Prone Areas in the Mississippian Leadville Limestone, Northern Paradox Basin, Utah

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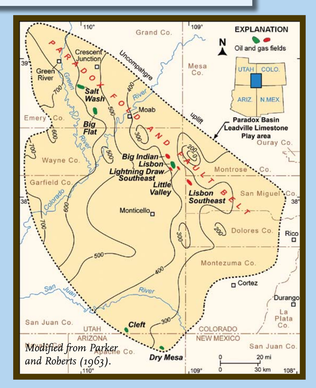
Abstract

Potential oil-prone areas for the Mississippian Leadville Limestone were identified in the northern Paradox Basin (Paradox fold and fault belt), Utah, based on hydrocarbon shows using low-cost epifluorescence techniques. The trapping mechanisms for Leadville producing fields are usually anticlines bounded by large, basement-involved normal faults. Epifluorescence microscopy is a technique used to provide information on diagenesis, pore types, and organic matter (including "live" hydrocarbons) within sedimentary rocks. It is a rapid, non-destructive procedure that uses a petrographic microscope equipped with reflected-light capabilities, a mercury-vapor light, and appropriate filtering.

Approximately 900 cutting samples were selected from 32 wells penetrating the Leadville Limestone (six gas, condensate, and oil wells, as well as 26 non-productive wells) throughout the region. These cuttings (generally four to ten samples per depth interval from each well) display intercrystalline porosity and occasional small vugs or molds. A qualitative visual rating (a range and average) based on epifluorescence evaluation was applied to the group of cuttings from each depth interval in each well. The highest average and highest maximum epiflourescence from each well were plotted and mapped.

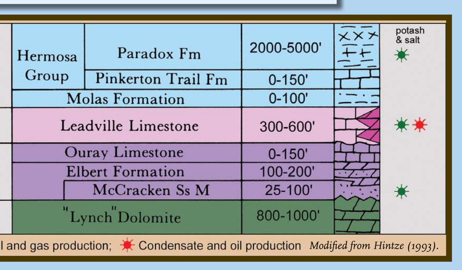
As expected, productive wells (fields) are distinguished by generally higher epifluorescence ratings. However, a regional southeast-northwest trend of relatively high epifluorescence parallels the southwestern part of the Paradox fold and fault belt while the northeastern part shows a regional trend of low epifluorescence. This implies that hydrocarbon migration and dolomitization were associated with regional northwest-trending faults and fracture zones, which created potential oil-prone areas along the southwest trend.

Location of Fields that Produce from the Mississippian Leadville Limestone, Utah and Colorado

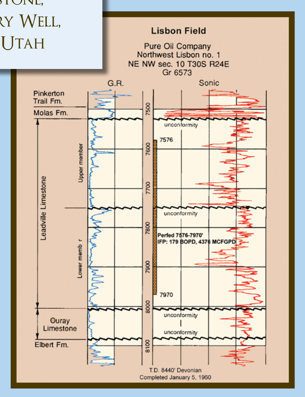


Thickness of the Leadville is shown; contour interval is 100 feet.

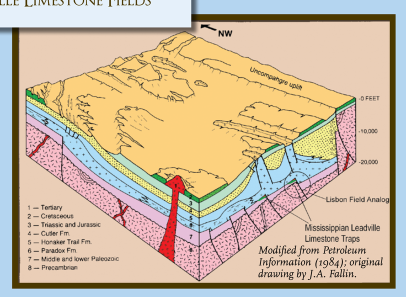
Stratigraphic Column of a Portion of the Paleozoic Section Determined from Subsurface Well Data in the Paradox Fold and Fault Belt, Grand and San Juan Counties, Utah



Typical Gamma Ray-Sonic Log of the Leadville Limestone, Lisbon Field Discovery Well, San Juan County, Utah



Schematic Block Diagram of the Paradox Basin Displaying Basement-Involved Structural Trapping Mechanisms for the Leadville Limestone Fields



Methods

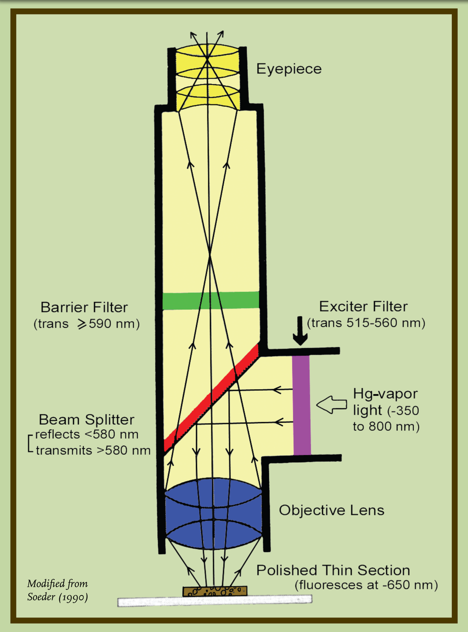
Epifluorescence microscopy has been used extensively within industry and research for enhancing petrographic observations, including the recognition of depositional and diagenetic fabrics within recrystallized limestone and massive dolomite. The study of pore structures, microfractures, and microporosity within both carbonates and sandstones has been greatly facilitated by impregnating these voids with epoxy spiked with fluorescing dyes. Epifluorescence petrography for this project used incident (reflected) blue-light fluorescence microscopy employing the use of the modified "white card" technique. Fluorescence data and observations collected for this study utilized a Jena (now part of Carl Zeiss) research-grade combination polarizing-reflected light microscope equipped with a high-pressure mercury vapor lamp for epifluorescence excitation, a Zeiss IIIRS epifluorescence nosepiece, and a 35-mm camera system. Magnification ranges for examination and photo-documentation were between about 130 and 320x. Blue light (about 420-490 nm exciter filter/520 nm barrier filter) was used to excite the cuttings and core-chip samples. We have found broad-band, blue-light epifluorescence to be the most helpful in observational work on dolomite, although some workers report applications using UV light (330-380 nm exciter filter/420 nm barrier filter) or narrow-band, blue-violet light (400-440 nm exciter filter/480 nm barrier filter). Finally, the greater depth of investigation into a sample by the reflected fluorescence technique than by transmitted polarized light or other forms of reflected light makes it possible to resolve grain boundary and compositional features that are normally not appreciated in cutting or thin-section petrography.

Wells penetrating the Leadville Limestone in the Utah part of the Paradox fold and fault belt were plotted and all Leadville well cuttings available from the collection at the Utah Core Research Center were compiled. Cuttings were examined under a binocular microscope and porous samples of dolomite and some limestone were selected from various zones over the Leadville section: generally four to ten samples per depth interval from each well. The cuttings were placed on Petrologs™, a small plastic, self-adhesive compartmentalized cutting storage unit, for epifluorescence examination. (All Petrologs™ containing Leadville cuttings from the project are stored at the Utah Core Research Center and are available to the public.) Thus, sample preparation is inexpensive and rapid.

Examination of cuttings included photo-documentation under epifluorescence and plane-polarized light at the same magnification. Photomicrography of the compositional, textural, and pore structure attributes was done using high-speed film (ISO 800 and 1600) with some bracketing of exposures as camera metering systems do not always reliably read these high-contrast images in the yellow and green light spectrum. Since the image brightness is directly proportional to magnification, the best images are obtained at relatively high magnifications (such as greater than 100X). Low-power fluorescence is often too dim to effectively record on film.

Epifluorescence petrography makes it possible to clearly identify hydrocarbon shows in Leadville cuttings selected for study. A qualitative visual rating scale (a range and average) based on epifluorescence evaluation was applied to the group of cuttings from each depth in each well. Using the qualitative visual rating scale, the highest maximum and highest average epifluorescence readings from each well were plotted and mapped.

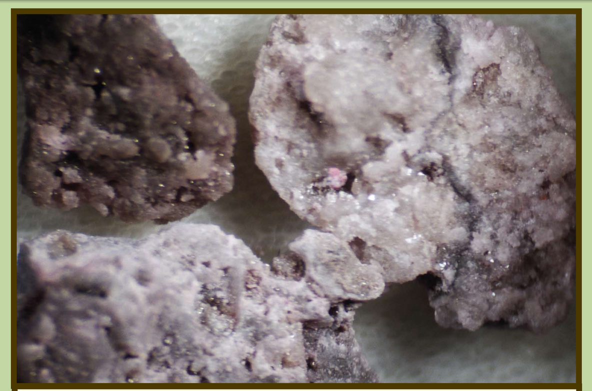
Generalized Microscope Optical Configuration for Observing Fluorescence Under Incident Light



Example of cuttings selected from various Leadville zones between 6875 to 7075 ft, Pure Mineral Point 1 well (section 7, T. 26 S., R. 18 E., Grand County), placed on Petrologs™ for epifluorescence examination.

Examples of Cuttings Selected from Various Leadville Zones as Observed with a Binocular Microscope

Overview of dolomite cuttings (16X) from 9410 to 9420 ft containing porosity and bitumen in the Pure Spiller Canyon State 1 well (SW1/4SW1/4 section 16, T. 30 S., R. 25 E., San Juan County).



Overview of dolomite cuttings (13X) from 7800 to 7810 ft containing porosity and stylolites in the Hatch Mesa 1 well (SE1/4SW1/4 section 22, T. 28 S., R. 21 E., San Juan County).

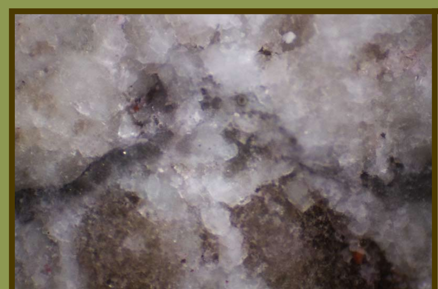
Overview of dolomite cuttings (12X) from 10,020 to 10,023 ft containing porosity and bitumen in the Pure USA Big Indian 1 well (SE1/4SE1/4 section 33, T. 29 S., R. 24 E., San Juan County).

Single white dolomite cutting (14X) with good intercrystalline porosity from 7790 to 7800 ft containing porosity and stylolites in the Hatch Mesa 1 well.

Close-Up Views of Petrographic Characteristics of Leadville Cuttings as Observed with a Binocular Microscope

Large, single sample of tight dolomite with widely spaced small vugs from 7780 to 7790 ft in the Hatch Mesa 1 well (SE1/4SW1/4 section 22, T. 28 S., R. 21 E., San Juan County).

Sample of white dolomite with good intercrystalline porosity from 7790 to 7800 ft contains bitumen in the Hatch Mesa 1 well; note possible sulfide replacement (opaque).

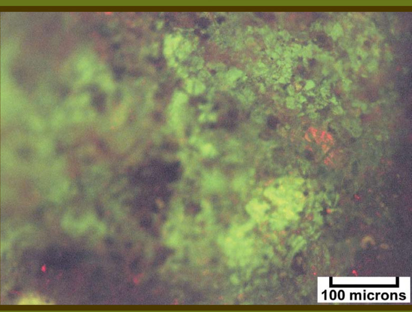


Sample showing stylolite overprinted with dolomite replacement from 7800 to 7810 ft in the Hatch Mesa 1 well; note possible sulfide replacement.

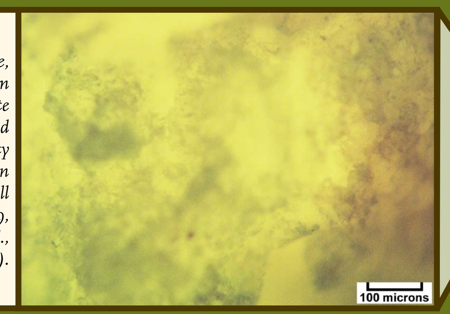
Sample showing dolomite containing small vugs and intercrystalline porosity lined with bitumen from 10,020 to 10,023 ft in the Pure USA Big Indian 1 well (SE1/4SE1/4 section 33, T. 29 S., R. 24 E., San Juan County).

Photomicrographs Under Moderate Magnification Showing Examples of Visually Rated Epifluorescence

Weak fluorescence, rated 1.0, medium to coarsely crystalline dolomite with fairly good bitumen-lined, intercrystalline porosity from 9150 to 9160 ft in the Pure Spiller Canyon 1 well (SW1/4SW1/4 section 16, T. 30 S., R. 25 E., San Juan County); note abundant iron distribution (red), bitumen is black.

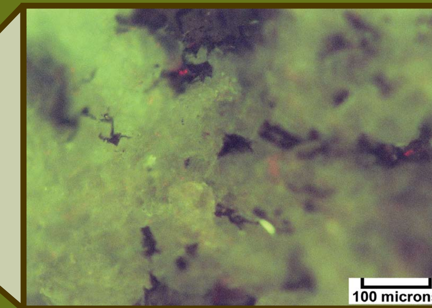


Bright fluorescence, rated 3.0, in medium crystalline dolomite with fair to good intercrystalline porosity from 5935 to 5945 ft in the Federal Hatt 1 well (SE1/4SE1/4 section 19, T. 23 S., R. 14 E., Emery County).



Key to the Epifluorescence Qualitative Visual "Rating" Scale

Rating	Generalized Interpretation
0 – 0.5	*No Fluorescence: Not capable of oil production. May be wet, if not a gas-bearing zone.*
1.0 – 1.5	*Weak Fluorescence: An "oil" show. Indicative of oil in the system, but not necessarily capable of production. Some dull or weak fluorescence may exist in a wet zone (especially if there is "speckled" fluorescence) or in a mixed oil/water zone.*
2.0 – 2.5	*Moderate Fluorescence: A good indication of oil within this zone. Probably capable of some oil production if there is adequate porosity and permeability.*
3.0 – 3.5	*Bright Fluorescence: A very good to excellent indication of oil within this zone. Should be capable of some oil production if there is adequate porosity and permeability.*
3.5 – 4.0	*Very Bright, Intense Fluorescence: Also a very good to excellent indication of oil within this zone. However, some very bright fluorescence may indicate very tight oil-bearing rocks or mature, oil-generating source rocks.*



No to very weak fluorescence, rated 0.2, medium to coarsely crystalline dolomite containing bitumen and iron from 10,020 to 10,023 ft in the Pure USA Big Indian 1 well (SE1/4SE1/4 section 33, T. 29 S., R. 24 E., San Juan County).

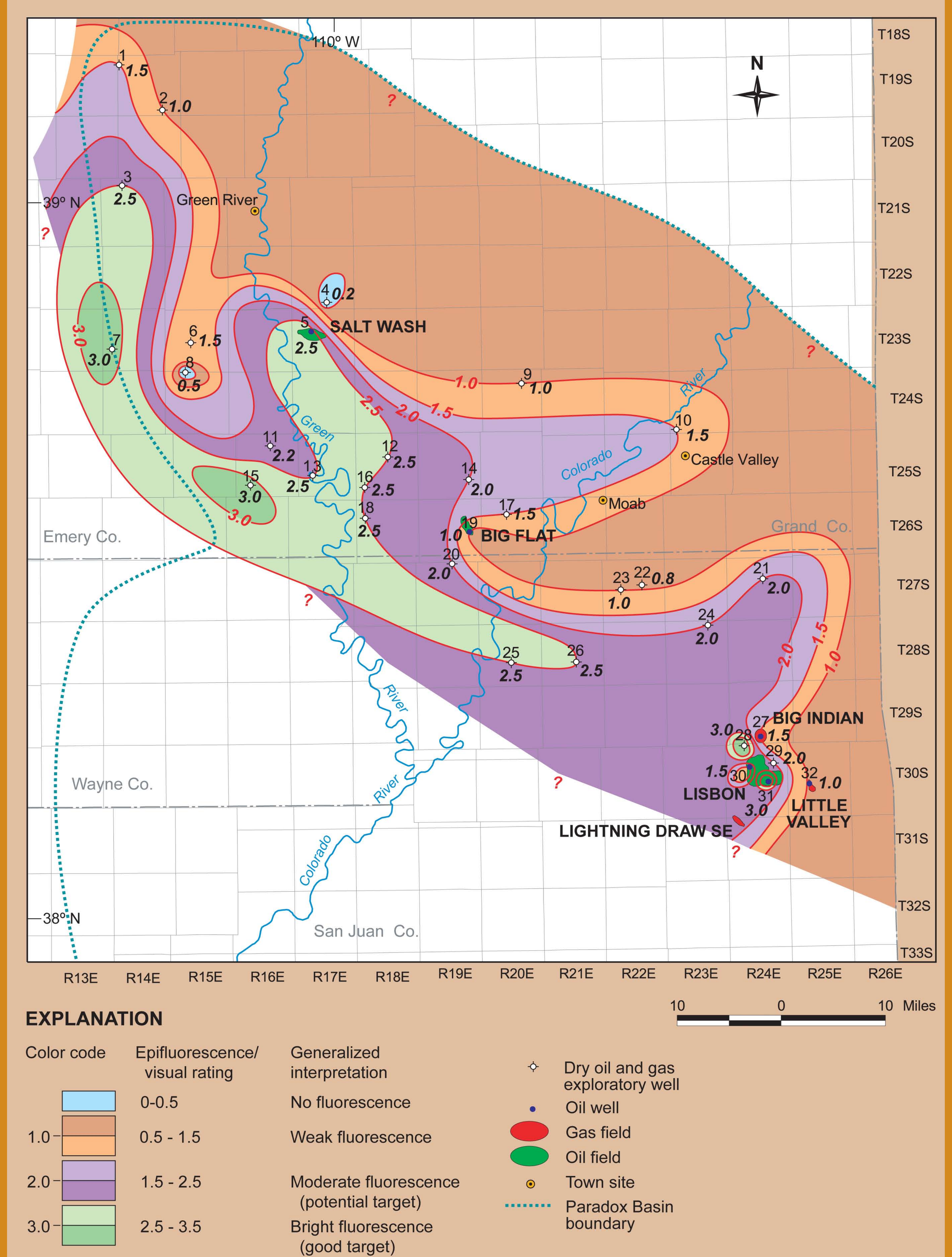
Moderate fluorescence, rated 2.0, fine to medium crystalline dolomite from 10,240 to 10,250 ft in the Gulf Muleshoe 1 well (section 2, T. 28 S., R. 23 E., San Juan County).

Wells in the Paradox Fold and Fault Belt, Utah, Containing Leadville Limestone Cuttings Evaluated Using Epifluorescence Techniques

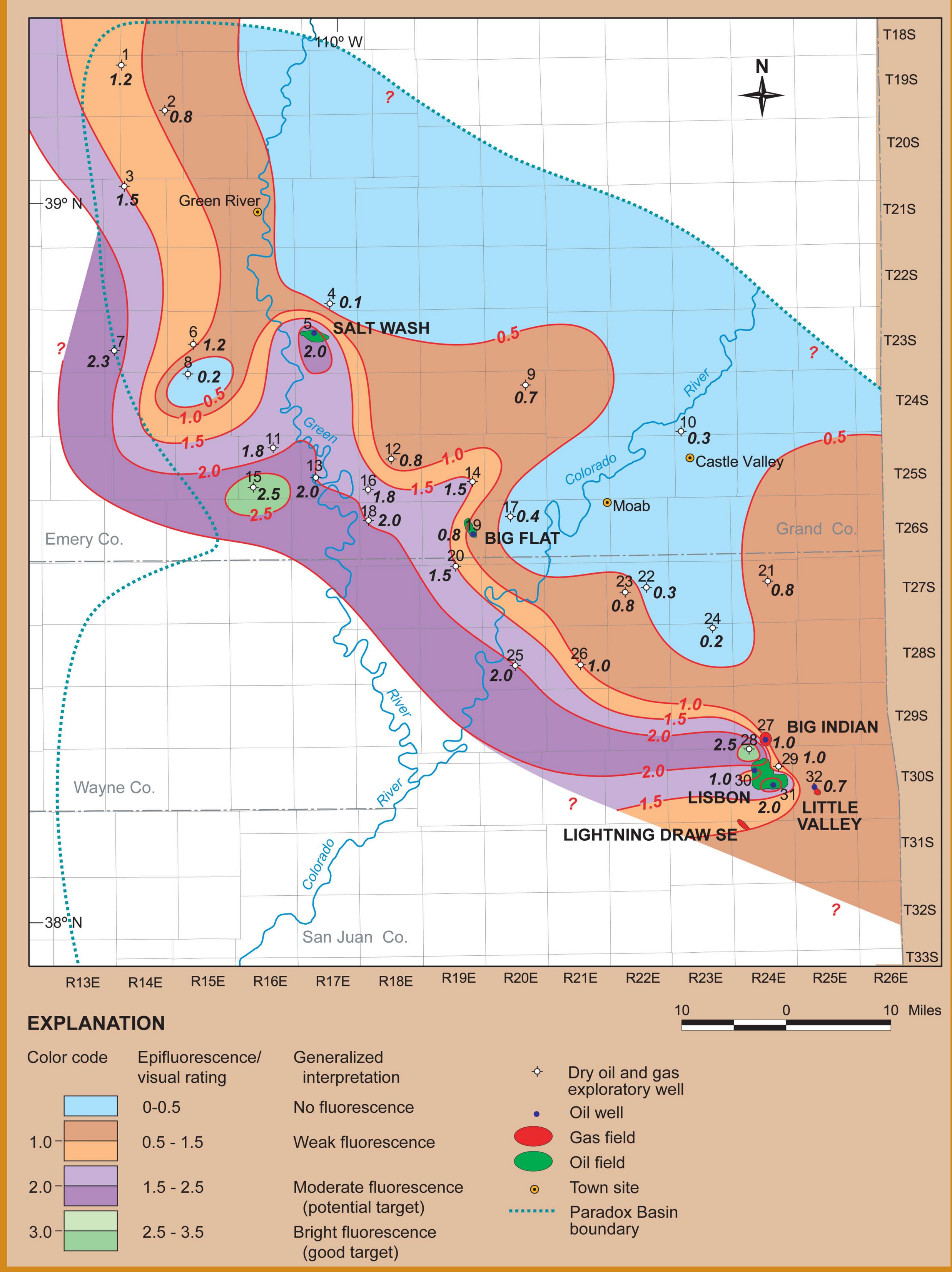
Map #	Well Name	Location	County	Interval (ft)	N*	Visual EF Rating: Highest Maximum	Visual EF Rating: Highest Average
1	Woodside 1	SESE 12 19S 13E	Emery	6580-6750	23	1.5	1.2
2	Hatch Sphinx Unit 1-A	SWNW 35 19S 14E	Emery	8670-8715	45	1.0	0.8
3	Denison Mines 5-1	5 21S 14E	Emery	5830-5870	23	2.5	1.5
4	Salt Wash 22-34	34 22S 17E	Grand	10,070-10,085	16	0.2	0.1
5	Government Smoot 1	CSENE 17 23S 17E	Grand	8732-8737	16	2.5	2.0
6	Chaffin 1	NENW 21 23S 15E	Emery	7460-7540	26	1.5	1.2
7	Federal Hatt 1	SESE 19 23S 14 E	Emery	5905-6020	33	3.0	2.3
8	Gov 45-5	5 24S 15E	Emery	6899-6935	5	0.5	0.2
9	State 12-11	SWNW 11 24S 20E	Grand	11,810-11,850	50	1.0	0.7
10	Federal 31	NWSE 31 24S 23E	Grand	10,450-10,760	27	1.5	0.3
11	Gruvers Mesa 2	10 25S 16E	Emery	6750-6910	32	2.2	1.8
12	McRae Fed 1	SWSW 10 25S 18E	Grand	8485-8550	8	2.5	0.8
13	Bow Knot Unit 1	NESE 20 25S 17.5E	Grand	6075-6400	31	2.5	2.0
14	Big Flat/Bartlett Flat 1	NENE 26 25S 19 E	Grand	8560-8650	17	2.0	1.5
15	Lookout Point 1	SWSW 29 25S 16E	Emery	6380-6520	22	3.0	2.5
16	Fed Bowknoll 1	NESE 30 25S 18 E	Grand	7375-7390	12	2.5	1.8
17	Long Canyon 1	NENW 9 26S 20E	Grand	7560-7630	44	1.5	0.4
18	Mineral Point 1	7 26S 18E	Grand	6875-7075	65	2.5	2.0
19	Big Flat 3	NENE 23 26S 19E	Grand	7714-7725	51	1.0	0.8
20	Federal Ornsby 1	NWNE 3 27S 19E	Wayne	7740-7810	25	2.0	1.5
21	Gold Basin 1	NWNW 15 27S 24E	San Juan	14,300-14,410	37	2.0	0.8
22	Putnam 1	SENE 15 27S 22 E	San Juan	7410-7490	30	0.8	0.3
23	Unit 1 Bridger Sack Mesa	SESE 17 27S 22 E	San Juan	7030-7070	53	1.0	0.8
24	Muleshoe 1	2 28S 23E	San Juan	10,240-10,280	9	2.0	0.2
25	Lockhard Fed 1	SW 22 28S 20E	San Juan	5130-5150	37	2.5	2.0
26	Hatch Mesa 1	SESW 22 28S 21E	San Juan	7780-7820	23	2.5	1.0
27	USA Big Indian 1	NWSESE 33 29S 24E	San Juan	9960-10,090	55	1.5	1.0
28	State 1	32 29.5S 24E	San Juan	9835-9852	16	3.0	2.5
29	NW Lisbon St. A	2 30S 24E	San Juan	9710-9725	12	2.0	1.0
30	Lisbon Valley C-1	NENW 9 30S 24E	San Juan	8765-8770	20	1.5	1.0
31	Lisbon 814-A	CNWSW 14 30S 24E	San Juan	8870-8930	80	3.0	2.0
32	Spiller Canyon State 1	SWSW 16 30S 25E	San Juan	9080-9420	75	1.0	0.7

*N = number of samples

Map of the Highest Maximum Epifluorescence Based on Visual Rating of Well Cuttings, Paradox Fold and Fault Belt, Utah



Map of the Highest Average Epifluorescence Based on Visual Rating of Well Cuttings, Paradox Fold and Fault Belt, Utah



Summary, Conclusions, and Recommendations

1. The Mississippian Leadville Limestone is a shallow, open-marine, carbonate-shelf deposit. The Leadville has produced over 53 million barrels (8.4 million m^3) of oil from seven fields in the Paradox fold and fault belt of the Paradox Basin, Utah and Colorado. Most Leadville oil and gas production is from basement-involved structural traps. All of these fields are currently operated by independent producers. This environmentally sensitive, 7500-square-mile (19,400 km^2) area is relatively unexplored. Only independent producers continue to hunt for Leadville oil targets in the region.

2. Epifluorescence petrography makes it possible to clearly identify hydrocarbon shows in Leadville cuttings selected for study. It is a non-destructive procedure that can be done using a petrographic microscope equipped with reflected light capabilities, mercury-vapor light, and appropriate filtering. Sample preparation is inexpensive and rapid.

3. Cuttings from 32 productive and dry exploratory wells penetrating the Leadville Limestone in the Utah part of the Paradox fold and fault belt were examined under a binocular microscope. Over 900 samples of porous dolomite and some limestone were selected from various zones over the Leadville section for epifluorescence evaluation.

4. Epifluorescence allows one to observe the presence or absence of any soluble hydrocarbons, especially in high porosity dolomite. Samples displaying fluorescence represent areas where hydrocarbons may have migrated or accumulated. If no fluorescence is observed in porous dolomites, the samples are also good representatives of areas where hydrocarbons have not migrated or accumulated.

5. A qualitative visual "rating" scale (a range and average) based on epifluorescence evaluation was applied to the group of cuttings from each depth in each well. The highest maximum and highest average epifluorescence readings from each well were plotted and mapped.

6. The maps show a regional southeast-northwest trend of relatively high epifluorescence for Leadville cuttings that parallels the southwestern part of the Paradox fold and fault belt from Lisbon field to west of the town of Green River. The northeastern part of the fold and fault belt shows a regional trend of low epifluorescence including a large area of essentially no epifluorescence centered around the town of Moab. As expected, productive Leadville wells have cuttings distinguished by generally higher epifluorescence readings.

7. Hydrocarbon migration and alteration dolomitization were associated with regional northwest-trending faults and fracture zones, which created potential oil-prone areas along the southwest trend. Hydrocarbons may have migrated from organic-rich shales in the Pennsylvanian Paradox Formation where they are in contact with the Leadville Limestone along faults. Hydrothermal alteration associated with these faults and related fracture zones may have generated late, porous dolomite and thus produced diagenetic traps. Hydrocarbons flushed out to the southwest by hydrodynamic processes may also account for the lack of significant epifluorescence in the northeast trend. In addition, these epifluorescence trends could be related to facies or karst development in the Leadville.

8. Exploration efforts should be concentrated in epifluorescence suggested oil-prone areas along the southwest part of the Paradox fold and fault belt.

Acknowledgments

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